Top quark pair production cross section at Tevatron

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An overview of the recent measurements of the top antitop quark pair production cross section in proton antiproton collisions at $\sqrt{s} = 1.96$ TeV in lepton + jets and dilepton final states is presented. These measurements are based on $1 - 2.8$ fb^{-1} of data collected with the D0 and CDF experiments at the Fermilab Tevatron collider. The cross section is measured with a precision close to 8 % and found to be compatible with the standard model prediction. Interpretations of the cross-section measurements for charge higgs search and for top quark mass measurement are also discussed.

1 Introduction

The measurements of the top antitop quark pair $(t\bar{t})$ production cross section are aimed to verify the agreement between the experimental data and the perturbative QCD calculation. Several approaches for the $t\bar{t}$ cross section calculation to the next-to-leading order are discussed in the literature [1,2,3,4]. All of them have a comparable uncertainty between 7 % and 10%. Any significant deviation from the predicted value or differences in the measured cross section in different final states may indicate the presence of effects beyond standard model.

Within the standard model (SM) the top quark decays to a W boson and b quark with a probability close to 100%. If both W bosons (from top and antitop quarks) decay to lepton-neutrino pairs, such final states will be referred to as the "dilepton" channel. If one of the W bosons decays to a pair of light quarks, then this final state will be referred to as the "lepton+jet" channel.

2 Dilepton final state

The decay signature of the dilepton final state consists of two leptons with large transverse momentum (p_T), two jets originating from b quarks and non-zero missing transverse energy $(\not{E}_T)$ due to the presence of neutrinos from W boson decays. This channel has the highest signal to background ratio of all $t\bar{t}$ final states, but also the lowest probability, $BR \sim 6.5\%$ for final states with e, μ or $\tau \rightarrow e, \mu$ and $BR \sim 3.6\%$ for final states with hadronically decaying τ lepton.

The main sources of background in this channel are Z boson $(Z/\gamma^\star \rightarrow l^+l^-)$ and diboson productions (WW, WZ and ZZ) with at least two charged leptons in the final state. Other important background contribution is W (+jets) and multijets production processes (so-called "instrumental background"). Semileptonic decays of b and c quarks, pion or kaon decays could lead to an additional muon in these processes. An additional electron or tau lepton could be present because of the jet misidentification. $Z/\gamma^\star$ and diboson background contributions are estimated as $N_{bckg} = \sigma_{theory}\varepsilon \int Ldt$, where σ_{theory} is a theoretical cross section, $\int Ldt$ is the

(1) dileptons, kinematic based approach $(2.8\ fb^{-1})$ [5] :	$\sigma_{t\bar{t}} = 6.7 \pm 0.8 \pm 0.4 \pm 0.4\ pb$
(2) dileptons, b-tagging approach $(2.8\ fb^{-1})$ [5] :	$\sigma_{t\bar{t}} = 7.8 \pm 0.9 \pm 0.7 \pm 0.45\ pb$
(3) lepton+jets, kinematic based approach $(2.8\ fb^{-1})$ [6] :	$\sigma_{t\bar{t}} = 7.1 \pm 0.4 \pm 0.4 \pm 0.4\ pb$
(4) lepton+jets, b-tagging $(2.7\ fb^{-1})$ [7]:	$\sigma_{t\bar{t}} = 7.2 \pm 0.4 \pm 0.5 \pm 0.4\ pb$
(5) alljets $(1.0\ fb^{-1})$ [8] :	$\sigma_{t\bar{t}} = 8.3 \pm 1.0^{+2.0}_{-1.5} \pm 0.5\ pb$
CDF combined, preliminary (2.8 fb^{-1}) [9] :	$\sigma_{t\bar{t}} = 7.0 \pm 0.6\ pb$

Table 1: $t\bar{t}$ cross section measurements by the CDF experiment. The first uncertainty is the statistical only, the second one is the systematic uncertainty and the last one is the uncertainty on the integrated luminosity. For the combined result all uncertainties are combined together. In all measurements m_t is assumed to be 175 GeV.

(1) dileptons $(1.0\ fb^{-1})$ [10] :	$\sigma_{t\bar{t}} = 7.5 \pm 1.0^{+0.7}_{-0.6} \pm 0.6\ pb\ (m_t = 170\ \text{GeV})$
(2) τ+lepton $(2.2\ fb^{-1})$ [11] :	$\sigma_{t\bar{t}} = 7.3^{+1.3}_{-1.2}\ ^{+1.2}_{-1.1} \pm 0.45\ pb\ (m_t = 170\ \text{GeV})$
(3) lepton+jets $(0.9\ fb^{-1})$ [12] :	$\sigma_{t\bar{t}} = 7.8 \pm 0.5 \pm 0.5 \pm 0.45\ pb\ (m_t = 175\ \text{GeV})$
(4) alljets $(0.4\ fb^{-1})$ [13] :	$\sigma_{t\bar{t}} = 4.5^{+2.0}_{-1.9}\ ^{+1.4}_{-1.1} \pm 0.3\ pb\ (m_t = 175\ \text{GeV})$
D0 combined, preliminary (1.0 fb^{-1}) [14] :	$\sigma_{t\bar{t}} = 8.2^{+1.0}_{-0.9}\ pb\ (m_t = 170\ \text{GeV})$

Table 2: $t\bar{t}$ cross section measurements by the D0 experiment. The first uncertainty is the statistical only, the second one is the systematic uncertainty and the last one is the uncertainty on the integrated luminosity. For the combined result all uncertainties are combined together.

integrated luminosity and ε is the selection efficiency calculated using MC simulation. Non of the existing MC generators can reproduce the $Z/\gamma^\star\ p_T$ distribution in data [15]. That is why this distribution is reweighted according to the data / MC difference measured in the sample $Z/\gamma^\star \to l^+l^-$. To estimate the instrumental background the CDF experiment assumes that the number of background events in the main sample (where both leptons have opposite charge) is equal to the number of events in the dilepton samples where both leptons have the same charge. In addition to the "same sign" approach the D0 collaboration also estimates the instrumental background from a sample with inverted quality on the lepton identification parameters.

The most recent CDF results are based on an integrated luminosity of $2.8\ fb^{-1}$ in three final states: ee, $e\mu$ and $\mu\mu$. Two approaches are used to increase the signal-to-background ratio. In the first approach at least one jet is required to be identified as a jet originating from a b quark ("b-tagging"). In the second approach a selection based purely on the kinematic properties of the final states is used. The measured cross section is listed in Table 1, results (1) and (2). The most recent D0 results use an integrated luminosity of $\sim 1\ fb^{-1}$ and include not only electron and muon final states, but also the final states with hadronically decaying tau leptons: ee, $e\mu$, $\mu\mu$, $e\tau$ and $\mu\tau$. The measured cross section is listed in Table 2, result (1). The cross section measurements in final states with hadronically decaying tau leptons are important to constrain non standard model contribution to the $t\bar{t}$ final states (see an example in section 4). The D0 $2.2\ fb^{-1}$ measurement in the $e\tau$ and $\mu\tau$ final states gives a value shown in Table 2, result 2.

3 Lepton + jets final state

The decay signature for the lepton+jets final state consists of one high p_T lepton, two b quark jets, two jets originating from the W boson decay and non-zero $\not{E}_T$ due to the presence of the neutrino from the leptonic decay of the second W boson. This channel has high branching ratio,
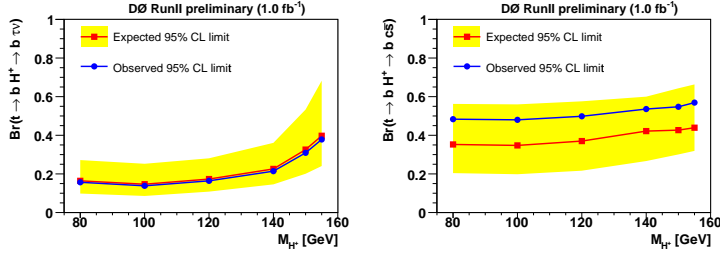
Figure 1: Upper limits on $B(t \to H^+ b)$ for tauonic (left) and lepto-phobic (right) H^+ decays. The yellow band shows the ± 1 standard deviation band around the expected limit.
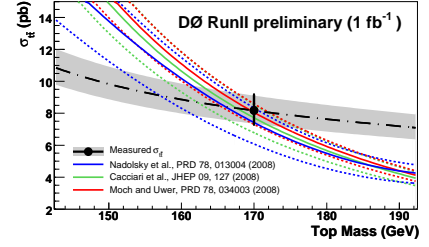
Figure 2: Experimental (point and black dashed line) and theoretical $\sigma_{t\bar{t}}$ as a function of m_t. The gray band is the total experimental uncertainty.

$BR \sim 35\%$ for final state including e, μ, $\tau \to e, \mu$ and $BR \sim 9.5\%$ for final states containing a hadronically decaying τ lepton. At the same time the background contribution in this final state is higher than in the dileptonic one. The main sources of background are W+jets and multijet production processes. In addition to the selection which require one high p_T lepton, at least three jets and high $\not{E}_T$, both experiments use two approaches to reduce the background contribution. The first one is based on the b quark jet identification and the second approach uses a multivariate discriminant built with kinematic information only. The multijet background is determined from a sample enhanced with multijet events by loosening the lepton identification criteria. The W+jets background distributions shapes are determined from MC simulation, but the overall normalization is adjusted to data. For W+jets simulation both experiments use the combination of matrix element generator Alpgen [16] with showering generator Pythia [17]. The heavy flavor contributions are adjusted by scaling up corresponding cross sections with scale factors determined from data. The $t\bar{t}$ cross sections measured by the CDF experiment with 2.8 fb^{-1} are shown in Table 1, results (3) and (4). The D0 0.9 fb^{-1} measurement which combine both b-tagging and kinematic based approaches is listed in Table 2, result (3).

The b-tagging approach provides a purer sample of $t\bar{t}$ events than the one using only kinematic information, but the systematic uncertainty of the cross section measurement is slightly higher, which is explained by the additional uncertainty due to the b quark identification procedure (5% for the CDF and 6% for D0). A better understanding of the b-tagging procedure may improve this uncertainty, but both approaches (the b-tagging and kinematic ones) will stay limited by the uncertainty on the integrated luminosity measurement , 5.8% for CDF, 6.1% for D0 (see complete systematic breakdown tables in [6,7,12]). That is why the CDF collaboration explores a new way of determining the $t\bar{t}$ cross section by measuring a ratio of $t\bar{t}$ to Z boson cross sections. This ratio is insensitive to the integrated luminosity uncertainty and "replaces" it with an uncertainty on the calculated value of the Z boson cross section. Using the Z boson cross section in the invariant mass range 66 – 116 GeV ($\sigma_Z = 251.3 \pm 5.0 \ pb$ [18]) the measured $t\bar{t}$ cross section is found to be [6,7]:

- kinematic based analysis: $\sigma_{t\bar{t}} = 6.9 \pm 0.4(stat) \pm 0.6(syst) \pm 0.1(theory) \ pb$, $m_t = 175$ GeV

- b-tagging analysis: $\sigma_{t\bar{t}} = 7.0 \pm 0.4(stat) \pm 0.4(syst) \pm 0.1(theory) \ pb$, $m_t = 175$ GeV

4 Interpretations of $t\bar{t}$ cross section measurements

The ratio of cross sections measured in different final states are particularly sensitive to new physics which may appear in top quark decays, especially if the boson from the top decay is not a W boson. For example, the decay into a charged Higgs boson ($t \to H^+ b$) as predicted in some models [19], can compete with the SM decay $t \to W^+ b$. Using the ratios

Theoretical computation	m_t (GeV)
NLO [1]	$165.5^{+6.1}_{-5.9}$
NLO+NLL [2]	$167.5^{+5.8}_{-5.6}$

Theoretical computation	m_t (GeV)
approximate NNLO [3]	$169.1^{+5.9}_{-5.2}$
approximate NNLO [4]	$168.2^{+5.9}_{-5.4}$

Table 3: Top quark mass at 68% C.L. for different theoretical computations of the $t\bar{t}$ cross section. Combined experimental and theoretical uncertainties are shown.

$\sigma(t\bar{t})_{dilepton}/\sigma(t\bar{t})_{lepton+jets}$ and $\sigma(t\bar{t})_{\tau+lepton}/\sigma(t\bar{t})_{dilepton\ \&\ lepton+jets}$ the D0 experiment extracts an upper limit on the branching ratio $B(t \to H^+ b)$ in case of the leptophobic ($H^+ \to c\bar{s}$) and tauonic ($H^+ \to \tau\nu$) models respectively [14]. The corresponding limits are shown in Fig. 1.

Another interesting interpretation of the $t\bar{t}$ cross section measurement is the extraction of the top quark mass using the theoretical dependence which relates cross-section with mass. This provides a measurement complementary to the direct top quark mass measurement, which is done in a well defined renormalization scheme, employed in the theoretical cross section calculation. Fig. 2 shows the D0 combined experimental and the theoretical [1,2,3] cross sections as a function of the top quark mass. Following the method in [10,12], the D0 collaboration extracts the top quark mass value at 68% CL. Since the theoretical calculations are performed in the pole mass scheme, this defines the extracted parameter here. The results [14] are given in Table 3. All values are in good agreement with the current world average of 173.1 ± 1.3 GeV [20].

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